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Assessment of Muscle Fatigue from TF Distributions of SEMG Signals

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ASSESSMENT OF MUSCLE FATIGUE FROM TF DISTRIBUTIONS OF SEMG SIGNALS

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ABSTRACT

Assessment of muscle fatigue involves the creation of indices based on the estimation of variables such as the instantaneous frequency (IF) and the instantaneous amplitude (IA), which can be estimated from a time-frequency (TF) distribution of a surface electromyographic signal (SEMG). Since during muscle fatigue there is a decrease of the IF and an increase of the IA, slopes from these parameters can be computed and used as indices to measure muscle fatigue. In this paper we present a comparison of four techniques used to build a TF distribution of SEMG signals, namely spectrogram, Wigner-Ville, Choi-Williams and smoothed pseudo Wigner-Ville. SEMG signals were recorded from thirty normal human subjects under specific physical routines to measure muscle fatigue, and TF distributions were computed for all the acquired signals. In order to confirm muscle fatigue, the computed indices were then correlated to the perceived discomfort levels reported by the subjects. Results show that although the spectrogram and smoothed pseudo Wigner-Ville have to overcome problems such as sizes of the time and frequency windows and cross terms, these two distributions provide equivalent slopes and valid indices of muscle fatigue for SEMG signals with low to medium nonstationarity.

ESTIMATION OF FREQUENCY AND AMPLITUDE FROM TF DISTRIBUTIONS

Muscle fatigue can be assessed from IF and IA of SEMG signals [1], [2], [3]. The approaches in the assessment of muscle fatigue have been restricted to the nature of the measured SEMG signal. If the SEMG signal is recorded during isometric constant force contractions, it is considered wide-sense stationary over time intervals lasting from 1 to 2 seconds [4]. Otherwise, if the SEMG signal is recorded during dynamic contractions, the signal is considered nonstationary [1], [4]. The spectrogram has been used to estimate the IF of SEMG signals with isometric contractions. In the case of nonstationary SEMG signals, not only the spectrogram but also other Cohen's class TF distributions, such as the Choi-Williams distribution (CWD) and the smoothed pseudo Wigner-Ville distribution (SPWVD) have been used to estimate the IF [1], [2]. However, in the assessment of muscle fatigue, we should analyze not only the IF but also the IA of the SEMG signal. The root mean square and the mean absolute value have been employed in the estimation of the IA of stationary and nonstationary SEMG signals [4], [6]. In this paper we compute both IF and IA from the spectrogram and the SPWVD – IF from the first order moment of the frequency distribution at a point in time and IA from the square root of the smoothed time marginal.

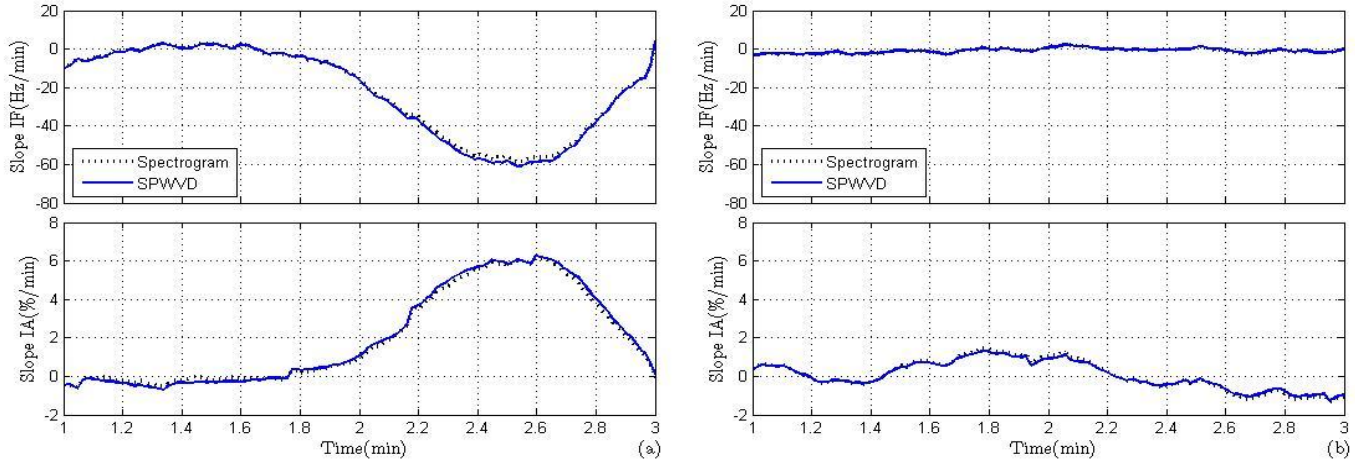
The implemented techniques for computing the TF distributions were evaluated based on aspects that are desired in SEMG analysis such as positivity, time and frequency marginals, and finite support. Also, an important desired characteristic is the suppression of cross terms since they lead to wrong estimates of the IF. Among the evaluated techniques, the spectrogram is computationally fast and the only always with a positive distribution. However, it shows a time-frequency localization trade-off and it does not hold the time and frequency marginals or the finite support [3], [4], [5]. On the other hand, the Wigner-Ville distribution (WVD) holds the time and frequency marginals and finite time support, but it is non-positive and leads to cross-terms when applied to multicomponent signals (as SEMG signals) [3], [4]. The

CWD and the SPWVD are obtained by convolving the WVD with different kernels, which make the WVD more local and reduce cross terms. The CWD holds time and frequency marginals and localization, but it is still not always positive, it has no time and frequency support, and its kernel depends on the choice of a critical parameter which has to be adapted for each signal [1]. Finally, the SPWVD can provide adequate estimates of the IF, but it does not hold the time and frequency marginals, finite support, and also leads to time-frequency localization trade-off.

EVALUATION OF MUSCLE FATIGUE

The SEMG signals used in this experiment were recorded from 30 normal human subjects who performed a 70% maximum voluntary contraction (MVC). This exertion was held until the subject could no longer maintain a 70% MVC or up to three minutes. The IF and the IA of the recorded signals were then estimated using the spectrogram, CWD, and SPWVD. However, since the CWD provided negative instantaneous frequencies, the measured IF from the CWD was not included in the evaluation of muscle fatigue. By employing a joint analysis of the spectrum and the amplitude (JASA) [6], slopes from the estimated IF and the IA were computed using a linear regression model and were calculated for one-minute intervals every one-second. Indices of muscle fatigue, recovery, increase force, and decrease force were then extracted from the slopes, and indices of muscle fatigue were correlated to the perceived discomfort levels reported by the subjects. The results for 2 out of 30 subjects are shown in Fig. 1. Figure 1(a) shows that the slopes for subject 1 at hour 6 reached a minimum of -60 Hz/min and a corresponding maximum of 6 %/min (percentage of the total amplitude), indicating the development of muscle fatigue. This matches the reported discomfort level. Subject 1 selected pain and severe hot spots in head, neck, shoulders, and back at the end of hour 6. Figure 1(b) shows small changes in the IF and IA for subject 2 at hour 1, indicating that fatigue was not present. This also matches the reported discomfort level. Subject 2 selected no discomfort and no hot spots in head, neck, shoulders and back at the end of hour 1.

Although the size of the time and frequency windows and the suppression of cross terms are important factors in the estimation of IF and IA, equivalent indices of muscle fatigue can be obtained from the spectrogram and the SPWVD, as indicated in the analysis of an extensive set of SEMG signals with low to medium nonstationarity.



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